V.0 STRATIFICATION

V.1 WHAT IS STRATIFICATION?

Stratification of a gas stream in a duct* is a condition in which one or more characteristics of the gas stream differ significantly over the cross-section of the duct. Stratification can be problematic for PM CEMS when establishing the initial correlation and meeting the correlation criteria of PS-11. In addition, changes in stratification over time can invalidate the correlation for the PM CEMS, resulting in PM CEMS responses that are not representative of PM emissions and in failure to meet the acceptance criteria for RCAs.

Stratification of gas streams can be defined in terms of pollutant concentration, velocity, temperature, or other characteristics. However, this section focuses on the stratification of PM concentrations, which is the characteristic of primary concern with PM CEMS. Most of the published literature on stratification concerns stratification of gases, such as SO_2 or NO_x. The EPA has defined gaseous pollutant stratification as a condition in which the concentration of a gaseous pollutant at a specific point in a duct differs from the average concentration of that pollutant over the cross-section of the duct by more than 10 percent. Several performance specifications published by EPA have incorporated a stratification test using this 10 percent criterion. Examples include PS-2 for SO_2 and NO_x CEMS and Appendix A to 40 CFR 75, Specifications and Test Procedures.

V.2 WHAT CAUSES STRATIFICATION?

The primary factors responsible for PM stratification are the size, mass density, and velocity of the particles; the duct configuration; and the degree of mixing in the gas stream. Particle shape also affects stratification, but in most cases, to a much lesser degree than do the other factors listed above. Stratification of PM usually results from a combination of these factors, so it can be misleading to discuss these factors independently of one another.

Stratification of PM is generally more severe than gaseous stratification because of the inertial forces that act on PM but do not affect gases. For a specific gas stream velocity, the magnitude of the inertial forces is largely a function of particle size and mass density. For particles with a uniform mass density, the smaller the particles, the weaker the inertial forces acting on those

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particles, and the more the particles behave like gases. Specifically, particles with diameters that are less 1.0 micrometers (µm) are assumed to behave as gases.[1] Stratification is more likely to occur in gas streams with particles that are larger than 1.0 µm, and the likelihood for stratification increases with increasing particle size. Any factor that affects particle size can also affect the severity of PM stratification. For example, in exhaust streams characterized by sticky particles, the likelihood of stratification downstream increases as the particles agglomerate and grow in size.

Because the inertial forces acting on particles are a function of particle mass density, mass density also affects the degree of stratification. Gas streams characterized by particles with higher mass density are more likely to be stratified because the inertial forces on the PM increase with increased particle mass density.

The velocity of the gas stream can affect PM stratification in two ways. For lower velocities in nonvertical ducts, the relative effect of gravity on particles in the gas stream is greater because the particles have more time to settle. As the particles settle, the PM concentration along the bottom or lower side of the duct increases, resulting in increasingly stratified flow. For vertical ducts, gravity does not affect stratification over the cross-section of a duct because gravity acts in the same direction (for downward flow) or opposite direction (for upward flow) of the PM as it flows through the duct.

The inertial forces on particles in an exhaust stream increase with increasing velocity. For straight ducts with no flow disturbances, the inertial forces on the particle do not induce stratification. However, these inertial forces become significant following bends, obstructions, or other disturbances that cause changes in the velocity or direction of the exhaust flow. In such cases, the higher the velocity of the gas stream, the greater the degree of PM stratification.

As explained in the previous paragraph, duct configuration can have a significant effect on PM stratification. Stratification of PM may become problematic following bends or changes in direction of ducts, where the momentum of the larger or more massive particles carries them to the far side of the duct wall immediately following the bend. The more abrupt the directional change, the more severe the stratification that is likely to occur. Other duct locations where PM stratification is likely to occur include the areas immediately following a junction where a secondary gas stream is introduced into the duct. If the concentration of the secondary stream differs from the PM concentration in the duct, stratification can occur until a downstream location in the duct where the combined flows are relatively well mixed.

For obvious reasons, the degree of mixing can significantly affect PM stratification. Stratification will not be a problem in any gas stream that is well mixed. Thus, the presence of baffles, vanes, or other devices that induce mixing will help to eliminate stratification in the gas stream.

V.3 WHERE IS STRATIFICATION LIKELY TO OCCUR?

Stratification is more likely to occur immediately downstream of a disturbance in a duct. Specifically, stratification can be present in the following locations:

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- Downstream of a bend,

- Downstream of any obstruction that results in changes in the velocity of the exhaust stream,

- Downstream of a junction in the duct where an additional exhaust or air stream is introduced to the duct,

- Along any nonvertical section of duct where the exhaust gas velocity is relatively low, and

- Along long sections of nonvertical ducts.

This is not meant to imply that stratification always is present downstream of a disturbance in the duct. As noted above, there are several factors that affect the degree of stratification. For example, if the PM in an exhaust stream consists of very fine particles (< 1.0 µm), the likelihood and severity of stratification are reduced. The distance downstream of the disturbance is also important. With the exception of relatively long horizontal ducts, the further downstream, the less severe the stratification is likely to be.

The degree of stratification is also highly dependent on particle size and mass density; exhaust gas streams with larger or more dense particles are more likely to experience stratification than exhaust streams with smaller or less dense particles. For this reason, knowledge of particle size distribution and other characteristics may be helpful in determining the likelihood of stratification in any particular duct.

V.4 HOW DOES STRATIFICATION AFFECT PM CEMS OPERATION?

If the PM concentration in a gas stream is stratified, the location of the PM CEMS probe (for extractive systems) or detector (for in situ systems) may not be representative of the average concentration in the cross-section of the duct. For example, in a stratified stack, the concentration of PM at the PM CEMS probe or detector may be 80 percent of the average PM concentration across the stack at that point. In such cases, the correlation equation will account for such a difference if the stratification does not change with changes in PM concentrations. That is, if the PM concentration at the probe or detector remains at or above 80 percent of the average PM concentration across the stack, the stratification will have no adverse effect on the PM CEMS correlation. Although the correlation equation is likely to be different, the correlation coefficient, confidence interval half range, and tolerance interval half range do not change.

In general, the correlation will account for the stratification if there is a numerical relationship between the PM CEMS response in the stratified duct and the PM CEMS response for the corresponding unstratified duct (i.e., what the PM CEMS responses would have been if the duct had not been stratified and the PM concentration at the PM CEMS probe or detector equaled the average PM concentration across the duct). Appendix A includes several examples that demonstrate this principle. In each of the examples, the correlation equation changes, but the

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If there is no such numerical relationship between the concentration at the probe or detector of the PM CEMS and the average PM concentration across the duct, it may not be possible to develop a correlation equation that satisfies the requirements of PS-11. In such cases, developing multiple correlations may solve the problem. Otherwise, the only options are to eliminate the stratification or move the PM CEMS probe or detector to a location where the PM concentrations are not stratified. The possible presence of stratification reinforces the need to perform the correlation test over the widest practical range of PM concentrations. The wider the range of concentrations, the more representative the correlation equation is likely to be.

Problems also can arise when the stratification changes with time as a result of changes in PM characteristics, such as particle size distribution, or changes in the exhaust and emission control system. For example, replacing an induced draft fan with another fan that changes the exhaust flow rate can give rise to changes in stratification. In cases where the stratification undergoes significant change, the original correlation equation for the PM CEMS may no longer be a reliable means of quantifying emissions, and it may be necessary to conduct a correlation test and develop a new PM CEMS correlation.

V.5 HOW DO I TEST FOR STRATIFICATION?

If PM stratification is suspected, a stratification test should be performed. Performance Specification 2 of Appendix B to 40 CFR 60 and Appendix A to 40 CFR 75 include procedures for evaluating gaseous pollutant stratification. Determining the presence of PM stratification in a duct can be carried out by following the same general steps specified for gaseous pollutants. For gaseous pollutants, sampling times as short as 2 minutes at each point may be adequate. To test for PM stratification, much longer sampling times at each point may be necessary. The basic procedure is to sample over the cross-section of the duct and compare the concentrations at each sampling point to the average concentration for the cross-section.[2] For rectangular ducts, a minimum of nine sampling points is recommended, with each point located at the centroid of similarly shaped, equal area divisions of the duct cross-section. For circular ducts, a minimum of 12 sampling points is recommended, with 6 sampling points along each of two traverses, as specified in 40 CFR 60, Appendix A, Method 1.

Isokinetic sampling should be used at all sampling points during a stratification test because sampling nonisokinetically can disrupt stratification patterns in the duct.[3] The minimum sampling time at each point is a function of the PM concentration and the sampling method. For example, if EPA Method 5 is used, sampling times of at least 15 minutes to 1 hour may be required at each point to collect a quantifiable PM sample on the filter. Longer sampling times help to ensure that the mass of PM collected can be accurately measured. On the other hand, the longer the sampling times, the more likely there will be variations in PM concentrations over the duration of the stratification test. Regardless of duration, the sampling times must be the same for each point.

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Rather than using a manual reference method to sample PM, it may be possible to use a PM CEMS. Even if a correlation between the PM CEMS and PM concentrations has not been established, the responses of the PM CEMS at the various sampling points across the stack can be compared to determine if there is a significant difference in PM concentrations across the stack. An advantage to using a PM CEMS instead of a manual method to test for stratification is that PM CEMS provide immediate results. In addition, much shorter sampling times may be adequate if a PM CEMS is used. As noted above, regardless of duration, the sampling times must be the same at each point when testing for stratification.

It is critical that the source is operated consistently (e.g., at constant load or process throughput) throughout the entire stratification test to ensure that PM concentrations do not vary significantly during the test. Control device operation also should be monitored carefully.

To ensure that there are no temporal variations in stratification, it is advisable to take separate independent PM concentration measurements at a stationary location throughout the entire stratification test, particularly if the test is scheduled to last several hours. To accomplish this, a second stationary probe connected to an independent sampling train or measurement system should be located at or near the centroid of the duct. One option is to use a PM CEMS as the stationary probe. If a manual method sampling train (e.g., Method 5) is used for the stationary measurements, the sampling conducted concurrently with each run of the traversing probe must also be treated as a separate test run for the stationary probe/sampling train. For example, upon the completion of sampling at each traverse point, the Method 5 stationary probe is removed and the sample recovery procedures specified in Section 4.2 of Method 5 are followed.

Following completion of the test, the PM concentration is determined for each sampling point. If a second, stationary probe was used, the PM concentrations also should be determined for each traverse point sampling period (e.g., if the sampling time was 15 minutes, the concentrations measured using the stationary probe should be determined for each corresponding 15-minute period). If the data from the stationary probe indicate that PM concentrations did not vary significantly over the test, the PM concentrations at each traverse point are then compared to the average of the PM concentrations for all sampling points to determine the percent stratification (S). This can be expressed by the following:

$$S = |c_i - c_{ave}| \times 100\%$$

where

S = percent stratification
c_i = PM concentration at sampling point i
c_{ave} = average PM concentration for all sampling points.

If the percent stratification is more than 10 percent for any traverse point, the duct is considered to be stratified at that location. However, as noted above, the presence of stratification does not necessarily have an adverse effect on the correlation. If the data from the second probe indicate significant variations in PM concentration over the course of the stratification test, the results

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An alternative method is to conduct a series of test runs using two sampling trains, one of which traverses the stack and the other is placed at the proposed location of the PM CEMS throughout the test. For each test run, the average PM concentration measured by the traversing probe is compared to the concentration measured by the stationary probe. If the concentrations are in good agreement, the PM CEMS location can be considered representative. However, the test should be repeated under a range of process operating conditions to provide some assurance that the location remains representative under normal operating conditions.

As explained previously, stratification per se may not be a problem because the correlation equation can account for differences in PM concentrations, provided there is a numerical relationship between the average concentration and the concentration at the PM CEMS probe or detector location (e.g., the PM concentration at the probe or detector remains a fixed percentage of the average PM concentration across the duct). Examples of this situation are provided in Appendix A. If there is no such relationship, it may not be possible to develop a correlation equation that satisfies PS-11 at that location. To determine if this is the case, the stratification test described above can be repeated for a range of PM concentrations. This can be a cost-prohibitive undertaking and other options may be preferred (e.g., select a different location for the PM CEMS).

V.6 WHAT CAN I DO IF I HAVE A STRATIFIED GAS STREAM?

If you suspect that PM stratification is occurring at a proposed PM CEMS sampling point, the primary options are as follows:

- Locate the PM CEMS probe or detector as proposed, assume that the correlation will account for the stratification, and verify the performance of the PM CEMS over time through RCAs;
- Eliminate the cause of the stratification;
- Select a location for the PM CEMS probe or detector where stratification is less likely; or
- If available, use a PM CEMS with a multipoint probe.

If you perform a stratification test and determine that the duct is stratified at the proposed location, you may decide to proceed with installing the PM CEMS at that location. In that case, it is recommended that you locate the probe or detector at a point where the PM concentration is comparable to the average PM concentration over the cross-section of the duct, which can be determined through a stratification test. Eliminating the cause of the stratification may not be practical, but it may be possible to modify or eliminate the obstruction or disturbance that causes the stratification. If you decide to select a different location for the PM CEMS probe or detector, you should take into consideration the various factors that affect stratification, as described above from the traversing probe are more difficult to interpret, and it may be necessary to repeat the stratification test.

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If the stratification appears to change with different process or control device operating conditions, it may be necessary to develop multiple correlations. Emissions could then be determined using the correlation equation that matches the operating condition.

V.7 REFERENCES

1. U.S. Environmental Protection Agency. 1997. *Handbook: Continuous Emission Monitoring Systems for Non-criteria Pollutants*. EPA/625/R-97/001. U.S. Environmental Protection Agency, Office of Research and Development.

2. Bivins, D. 1994. *Determination of the Presence of Stratification of Gaseous Pollutant and Diluent Emissions for Continuous Emission Monitor or Reference Method Relative Accuracy Locations*. EMC GD-025. U.S. Environmental Protection Agency, Emission Measurement Center.

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Appendix A

Examples of Correlation with Stratified PM Concentrations

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Examples of Correlation with Stratified PM Concentrations

Example 1

For this example, assume that the PM CEMS is located in an unstratified stack, and the PM concentration at the probe or detector is the same as the average PM concentration across the stack. The results of the initial correlation test are summarized in Table A-1, and Table A-2 shows the correlation equation developed from the data and the values for the relevant linear correlation parameters developed from the regression analysis.

Table A-1. Summary of Correlation Test Data

Run no.	PM CEMS response, mA (x)	PM concentration, mg/acm (y)
1	4.9	2.1
2	7.6	2.9
3	7.8	5.1
4	9.2	4.8
5	10.1	2.9
6	11.1	6.3
7	18.2	8.4
8	15.7	4.9
9	24.1	8.7
10	24.7	12.6
11	29.1	16.2
12	29.3	13.5
13	30.5	15.9
14	27.1	14.4
15	19.8	12.1

Table A-2. Results of Linear Regression Analysis

Parameter	Criterion	Results
Correlation equation		$\hat{y} = -0.633 + 0.521x$
Correlation coefficient (r)	≥ 0.85	0.94
Confidence interval half range (CI)	≤ 10%	4.7%
Tolerance interval half range (TI)	≤ 25%	14.8%

Example 1

For this example, assume that the PM CEMS is located in an unstratified stack, and the PM concentration at the probe or detector is the same as the average PM concentration across the stack. The results of the initial correlation test are summarized in Table A-1, and Table A-2 shows the correlation equation developed from the data and the values for the relevant linear correlation parameters developed from the regression analysis.

Table A-1. Summary of Correlation Test Data

Run no.	PM CEMS response, mA (x)	PM concentration, mg/acm (y)
1	4.9	2.1
2	7.6	2.9
3	7.8	5.1
4	9.2	4.8
5	10.1	2.9
6	11.1	6.3
7	18.2	8.4
8	15.7	4.9
9	24.1	8.7
10	24.7	12.6
11	29.1	16.2
12	29.3	13.5
13	30.5	15.9
14	27.1	14.4
15	19.8	12.1

Table A-2. Results of Linear Regression Analysis

Parameter	Criterion	Results
Correlation equation		$\hat{y} = -0.633 + 0.521x$
Correlation coefficient (r)	≥ 0.85	0.94
Confidence interval half range (CI)	≤ 10%	4.7%
Tolerance interval half range (TI)	≤ 25%	14.8%

Now assume the stack is stratified, and the probe for the PM CEMS is placed in a location where each PM CEMS response (x′) is 80 percent of the corresponding response (x) for unstratified conditions (i.e., 80 percent of each of the x values listed in Table A-1). Table A-3 shows the equivalent data for the correlation test, and Table A-4 shows the parameters for the linear correlation equation developed from the data with and without the stratification.

Table A-3. Summary of Correlation Test Data at 80% Response

Run no.	PM CEMS response, mA ($x' = 0.80x$)	PM concentration, mg/acm (y)
1	3.9	2.1
2	6.1	2.9
3	6.2	5.1
4	7.4	4.8
5	8.1	2.9
6	8.9	6.3
7	14.6	8.4
8	12.6	4.9
9	19.3	8.7
10	19.8	12.6
11	23.3	16.2
12	23.4	13.5
13	24.4	15.9
14	21.7	14.4
15	15.8	12.1

Table A-4. Results of Linear Regression Analysis for 80% Response

Parameter	Criterion	Results: No stratification	Results: $x' = 0.80x$
Correlation equation		$\hat{y} = -0.633 + 0.521x$	$\hat{y} = -0.633 + 0.652x$
Correlation coefficient (r)	≥ 0.85	0.94	0.94
Confidence interval half range (CI)	≤ 10%	4.7%	4.7%
Tolerance interval half range (TI)	≤ 25%	14.8%	14.8%

Now assume the stack is stratified, and the probe for the PM CEMS is placed in a location where each PM CEMS response (x′) is 80 percent of the corresponding response (x) for unstratified conditions (i.e., 80 percent of each of the x values listed in Table A-1). Table A-3 shows the equivalent data for the correlation test, and Table A-4 shows the parameters for the linear correlation equation developed from the data with and without the stratification.

Table A-3. Summary of Correlation Test Data at 80% Response

Run no.	PM CEMS response, mA ($x' = 0.80x$)	PM concentration, mg/acm (y)
1	3.9	2.1
2	6.1	2.9
3	6.2	5.1
4	7.4	4.8
5	8.1	2.9
6	8.9	6.3
7	14.6	8.4
8	12.6	4.9
9	19.3	8.7
10	19.8	12.6
11	23.3	16.2
12	23.4	13.5
13	24.4	15.9
14	21.7	14.4
15	15.8	12.1

Table A-4. Results of Linear Regression Analysis for 80% Response

Parameter	Criterion	Results: No stratification	Results: $x' = 0.80x$
Correlation equation		$\hat{y} = -0.633 + 0.521x$	$\hat{y} = -0.633 + 0.652x$
Correlation coefficient (r)	≥ 0.85	0.94	0.94
Confidence interval half range (CI)	≤ 10%	4.7%	4.7%
Tolerance interval half range (TI)	≤ 25%	14.8%	14.8%

Although the slope of the correlation equation is different, the correlation coefficient, confidence interval half range, and tolerance interval half range are unchanged.

Example 2

In the previous example, the PM concentration at the PM CEMS probe varied linearly with the average PM concentration across the stack at any given time such that the PM CEMS response was a constant 80 percent of what the response would have been if the probe were located where the PM concentration was equal to the average PM concentration across the stack. In this example, assume that a nonlinear relationship exists between the PM CEMS response (x′) and the response (x) for the corresponding unstratified stack. Specifically, the PM CEMS response varies according to the following:

$$x' = x^{0.8}$$

where

x' = PM CEMS response values during the correlation test
x = PM CEMS response values if the probe had been located where the PM concentration equaled the average PM concentration across the stack.

Table A-5 shows the equivalent data for the correlation test, and Table A-6 shows the parameters for the correlation equation developed from the data with and without the stratification. Although the correlation equation is quite different for the stratified stack, the other correlation parameters are essentially unchanged.

Table A-5. Summary of Correlation Test Data for Example 2

Run no.	PM CEMS response, mA ($x' = x^{0.8}$)	PM concentration, mg/acm (y)
1	3.6	2.1
2	5.1	2.9
3	5.2	5.1
4	5.9	4.8
5	6.4	2.9
6	6.8	6.3
7	10.2	8.4
8	9.1	4.9
9	12.8	8.7

Although the slope of the correlation equation is different, the correlation coefficient, confidence interval half range, and tolerance interval half range are unchanged.

Example 2

In the previous example, the PM concentration at the PM CEMS probe varied linearly with the average PM concentration across the stack at any given time such that the PM CEMS response was a constant 80 percent of what the response would have been if the probe were located where the PM concentration was equal to the average PM concentration across the stack. In this example, assume that a nonlinear relationship exists between the PM CEMS response (x') and the response (x) for the corresponding unstratified stack. Specifically, the PM CEMS response varies according to the following:

$$x' = x^{0.8}$$

where

x' = PM CEMS response values during the correlation test
x = PM CEMS response values if the probe had been located where the PM concentration equaled the average PM concentration across the stack.

Table A-5 shows the equivalent data for the correlation test, and Table A-6 shows the parameters for the correlation equation developed from the data with and without the stratification. Although the correlation equation is quite different for the stratified stack, the other correlation parameters are essentially unchanged.

Table A-5. Summary of Correlation Test Data for Example 2

Run no.	PM CEMS response, mA ($x' = x^{0.8}$)	PM concentration, mg/acm (y)
1	3.6	2.1
2	5.1	2.9
3	5.2	5.1
4	5.9	4.8
5	6.4	2.9
6	6.8	6.3
7	10.2	8.4
8	9.1	4.9
9	12.8	8.7

Table A-5. (continued)

Run no.	PM CEMS response, mA ($x' = x^{0.8}$)	PM concentration, mg/acm (y)
		(continued)
10	13	12.6
11	14.8	16.2
12	14.9	13.5
13	15.4	15.9
14	14	14.4
15	10.9	12.1

Table A-6. Results of Linear Regression Analysis for Example 2

Parameter	Criterion	Results	
		No stratification	$x' = x^{0.8}$
Correlation equation		$\hat{y} = -0.633 + 0.521x$	$\hat{y} = -2.51 + 1.14x$
Correlation coefficient (r)	≥ 0.85	0.94	0.94
Confidence interval half range (CI)	≤ 10%	4.7%	4.8%
Tolerance interval half range (TI)	≤ 25%	14.8%	15.2%

Example 3

This example is similar to Example 2 except that in this example, the relationship between the PM CEMS response and the response for an unstratified stack is expressed as

$$x' = x^{1.2}$$

where

x' = PM CEMS response values during the correlation test
x = PM CEMS response values if the probe had been located where the PM concentration equaled the average PM concentration across the stack.

The correlation test data are summarized in Table A-7. The results of the linear regression analysis are shown in Table A-8. As indicated in Table A-8, the correlation equation differs

Table A-5. (continued)

Run no.	PM CEMS response, mA ($x' = x^{0.8}$)	PM concentration, mg/acm (y)
		(continued)
10	13	12.6
11	14.8	16.2
12	14.9	13.5
13	15.4	15.9
14	14	14.4
15	10.9	12.1

Table A-6. Results of Linear Regression Analysis for Example 2

		Results	
Parameter	**Criterion**	**No stratification**	$x' = x^{0.8}$
Correlation equation		$\hat{y} = -0.633 + 0.521x$	$\hat{y} = -2.51 + 1.14x$
Correlation coefficient (r)	≥ 0.85	0.94	0.94
Confidence interval half range (CI)	≤ 10%	4.7%	4.8%
Tolerance interval half range (TI)	≤ 25%	14.8%	15.2%

Example 3

This example is similar to Example 2 except that in this example, the relationship between the PM CEMS response and the response for an unstratified stack is expressed as

$$x' = x^{1.2}$$

where

x' = PM CEMS response values during the correlation test
x = PM CEMS response values if the probe had been located where the PM concentration equaled the average PM concentration across the stack.

The correlation test data are summarized in Table A-7. The results of the linear regression analysis are shown in Table A-8. As indicated in Table A-8, the correlation equation differs significantly from the equation developed from the unstratified stack data. However, there are only minor differences in the two sets of results for the correlation coefficient, confidence interval half range, and tolerance interval half range.

Table A-7. Summary of Correlation Test Data for Example 3

Run no.	PM CEMS response, mA ($x' = x^{1.2}$)	PM concentration, mg/acm (y)
1	6.7	2.1
2	11.4	2.9
3	11.8	5.1
4	14.3	4.8
5	16	2.9
6	17.9	6.3
7	32.5	8.4
8	27.2	4.9
9	45.5	8.7
10	46.9	12.6
11	57.1	16.2
12	57.6	13.5
13	60.4	15.9
14	52.4	14.4
15	36	12.1

Table A-8. Results of Linear Regression Analysis for Example 3

		Results	
Parameter	**Criterion**	**No stratification**	$x' = x^{1.2}$
Correlation equation		$\hat{y} = -0.633 + 0.521x$	$\hat{y} = 0.609 + 0.246x$
Correlation coefficient (r)	≥ 0.85	0.94	0.94
Confidence interval half range (CI)	≤ 10%	4.7%	4.6%
Tolerance interval half range (TI)	≤ 25%	14.8%	14.5%

significantly from the equation developed from the unstratified stack data. However, there are only minor differences in the two sets of results for the correlation coefficient, confidence interval half range, and tolerance interval half range.

Table A-7. Summary of Correlation Test Data for Example 3

Run no.	PM CEMS response, mA ($x' = x^{1.2}$)	PM concentration, mg/acm (y)
1	6.7	2.1
2	11.4	2.9
3	11.8	5.1
4	14.3	4.8
5	16	2.9
6	17.9	6.3
7	32.5	8.4
8	27.2	4.9
9	45.5	8.7
10	46.9	12.6
11	57.1	16.2
12	57.6	13.5
13	60.4	15.9
14	52.4	14.4
15	36	12.1

Table A-8. Results of Linear Regression Analysis for Example 3

		Results	
Parameter	Criterion	No stratification	$x' = x^{1.2}$
Correlation equation		$\hat{y} = -0.633 + 0.521x$	$\hat{y} = 0.609 + 0.246x$
Correlation coefficient (r)	≥ 0.85	0.94	0.94
Confidence interval half range (CI)	≤ 10%	4.7%	4.6%
Tolerance interval half range (TI)	≤ 25%	14.8%	14.5%